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HIGH INTEGRITY CUPRO-NICKEL CASTINGS FOR TECHNOLOGY DEMONSTRATION AND SEA-WATER SERVICE EVALUATION

by

M. Sahoo[1], J.O. Edwards[2], L.J. Beke[3] and Z. Szanto[4]

ABSTRACT

As a sequel to laboratory studies on the foundry technology of niobium-modified cupro-nickel alloys, a "ship's set" of eight individual castings was made in a commercial foundry. Castings were made of both 70/30 and 90/10 cupro-nickel alloys, and each casting weighed approximately 34 kg (75 lb) after fettling.

This paper describes the design of gating and risering systems, and melting procedures for these castings, and the progressive changes in mould rigging which improved the quality of the castings.

The final production of sixteen castings of seven different designs in the two alloys, met the Canadian Department of National Defence specifications for the various ship-board components.

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MICROMEDIA

INTRODUCTION

Copper-base castings for marine service are traditionally made from tin bronzes because of their excellent corrosion resistance and other desirable properties. These alloys are, however, very prone to shrinkage porosity which reduces the mechanical properties of the castings and results in large variations in properties between castings. Consequently, there is concern about the reliability of individual castings, subjected to shock loading in naval vessels.

In response to a need for improved materials, PMRL/CANMET, supported by Department of National Defence - Chief of Research and Development (DND-CRAD), studied the foundry technology and characteristics of high-strength cupro-nickel alloys (1-4). The results of this work were presented to the Canadian foundry industry at a Copper Alloy Foundry Workshop, held at PMRL in 1979. As a practical sequel to this earlier work, the Chief of Engineering and Maintenance at DND (DND-CEM), requested that PMRL provide technical support to obtain from Canadian sources two ship's sets, each of 8 large cast manifolds, in niobium-modified 90/10 and 70/30 cupro-nickel. The cupro-nickel castings will replace existing tin-bronze castings for an evaluation of the new alloys under service conditions.

After discussions with several leading bronze foundries, a contract was placed with Burnstein Castings Ltd., St. Catherines, Ontario which in addition to supplying a strategic need from Canadian sources would help upgrade the technological capability of the Canadian foundry industry.

DESCRIPTION OF THE CASTINGS

All eight castings are essentially elbows of different orientation with one or two large inlets and four smaller outlets. Because the designs of the eight castings are similar, attention is focused in this paper on two typical castings only. Photographs of the patterns are shown in Figs. 1 and 2. As can be deduced from these and subsequent figures, the physical layout of the pattern and hence, the moulding method, had a major influence on gating and risering.

The specifications for the castings were:

(a) air-pressure test at 50 psi (345 kPa) before machining,
(b) radiographic inspection to level 2 of ASTM E272 (5),

(c) proof (water) pressure test at 400 psi (2760 kPa) after machining,

(d) composition limits and mechanical properties of separately cast test-bars conforming to ASTM B369-78 for alloys C96200 (90/10 Cu-Ni) and C96400 (70/30 Cu-Ni).

EXPERIMENTAL PROCEDURES

MELTING

After preliminary discussion between PMRL and Burnstein Castings, melting was carried out in a lift-coil induction furnace using 210 lb (95 kg)-capacity clay-graphite crucibles, coated with zircon. The graphite or steel rods used for stirring or plunging alloying elements were also coated with zircon. All melts were conducted in an oxidizing atmosphere using Cuprex flux. Foseco Slax-30B slag coagulant was used to thicken the flux residues, to aid skimming and prevent slag entrainment in the metal stream.

The charge consisted of pre-alloyed 70/30 Cu-Ni ingots, "in-house" scrap consisting of runners, gates and risers which were clean and reasonably free of sand, and electrolytic Mn. Additions of Si and Nb were made as Si-Fe and Nb-Fe master alloys containing respectively 95% Si and 55% Nb.

Melts of 90/10 Cu-Ni were made from the same base using the same techniques, but appropriate amounts of electrolytic tough-pitch copper and master alloys were added.

The general melting procedure consisted of charging the crucible with Cu-Ni scrap and ingots, and also pure Cu, and then heating under full power to 1300 or 1400 C (2370 or 2550 F) for 90/10 and 70/30 Cu-Ni melts respectively. Cuprex flux weighing about 2 lb (0.9 kg) was spread after the charge started to melt. When the required temperature was reached, manganese, ferro-silicon and ferro-niobium were added to the melt, followed by the spreading of 1 lb (0.5 kg) of Slax-30B. The melt was then deoxidized by plunging one Foseco No. 6 deoxidizing tube weighing about 4 oz (120 g). After skimming the Slax cover, the crucible was transferred to the pouring area. Before pouring, the melt was desulphurized by plunging about 0.04% Mg. The pouring temperature was 1250 C (2300 F) for the 90/10 and 1350 C (2450 F) for the 70/30 Cu-Ni melts

The reduced-pressure gas test conducted on site, indicated a very low gas content for the melts (7). The time taken for melting and casting

was about 70 min. The castings were allowed to cool in the moulds for at least 2 h before being shaken out.

MOULDING

CO_2 moulds and oil cores (baked) were used for all the castings. The moulding time varied from 2 to 4 h depending on the casting design. Similarly, the core-making time was about 2 - 3 h. In addition, the cores were twice baked for 3.5 h at a temperature of 230 C (450 F). The cores were usually vented. The cope and drag-box size was 36 x 24 in. (914 x 610 mm). The cope and drag heights varied between 6 and 8 in. (152 and 203 mm) depending on the flange diameter. This is also reflected in the variation in the sprue height.

All the melts generally conformed to the composition limits for alloys C96200 (90/10 Cu-Ni) or C96400 (70/30 Cu-Ni) specified in ASTM B369-78 except that the Fe content of each of the 90/10 melts was below the specified minimum (6). Fe is added to improve the impingement-corrosion resistance and for grain refinement.

GATING SYSTEM

In each case the design of the gating system included a tapered sprue with a sump at the bottom and a pouring basin. The gating system for each casting is given in Table 1 and can be seen in the various figures. Dross traps were used at the ends of runners.

The 90/10 Cu-Ni alloys have a freezing range of 20°C (36°F) and can be classified as short freezing-range alloys. However, the 70/30 Cu-Ni alloys have a solidification range of 50°C (90°F) and are likely to show fine interdendritic shrinkage. Hence, it was decided to confine the trial runs to 70/30 Cu-Ni alloys to develop the gating and risering systems.

The aim was to use a non-pressurized gating system with a gating ratio of 1:2:3 and a pouring rate of ~4.5 lb/sec (2 kg/sec). However, for the gating system shown in Figs. 3 and 4 and Table 1 (melts 1 and 2), the pouring basin was never full and the mould filled too quickly. The high flow rate for this sprue size was contrary to PMRL experience using offset pouring boxes. It was concluded that this was a dynamic effect of pouring directly into the sprue in the foundry. Consequently, the sprue cross-sectional area was reduced in subsequent castings. To improve the hot-metal distribution,

runners were placed on both sides of the casting, and gated through all side risers (Figs. 6, 9, and 11). This also helped to reduce the velocity of metal flow into the casting. To obtain a uniform metal flow through the gates, the runner cross-section was reduced by the area of each gate. In addition, the following precautions were taken:

(i) Junction between sprue and runner and between sprue well and runner was radiused to promote streamline flow.

(ii) Sharp bends in the runner system were avoided (see Fig. 11).

(iii) Dross traps were used at the ends of runners, the volume of each trap being equal to that of the sprue well.

RISERING SYSTEM

The procedures used in designing a risering system have been described in detail elsewhere (3). An important relation between thickness T, and feeding distance D, is (9)

$$D = 5.8\ T^{\frac{1}{2}} \qquad (1)$$

This equation is used to decide the number of risers to be used. When this was established, the riser size was determined by the NRL method developed by Pellini et al (10). To facilitate the calculation of riser size, each casting was divided into a number of sections, e.g. flange, nozzles, body, mounting legs, etc., and the riser size for each section was calculated separately. The short feeding distance for the Cu-Ni alloys (3-5 in. or 76-127 mm) warranted the use of chills at a number of locations to minimize the influence of inaccessible hot spots. This also helped to increase the casting yield significantly. The calculations showed that cylindrical risers, 2.5 in. (63 mm) diam x 4 in. (102 mm) high, provide adequate feeding. To limit the riser height to 4 in. (102 mm), blind risers were used in most cases. The top of each blind riser was covered with exothermic compound and core sand. Foseco insulating sleeves were used for all risers. After pouring, open risers were covered with insulating topping to reduce the rate of heat loss.

Cast-iron chills, where used, were located ¼ in. (6 mm) below the mould surface to eliminate "chill blows". The dimensions of the chills were 1½ x 1 x 1 in. (38 x 25 x 25 mm) for the flanges (drag half only), 1 x 1 x 3/4 in. (25 x 25 x 19 mm) for the nozzles, and 2 x 2 x 1 in. (51 x 51 x 25 mm) for the square flanges (casting 57-2) and mounting legs (casting 54). Chil-ling of the nozzles was further enhanced by the use of chromite sand in

the cores in this area. For nozzles connected to risers, the chromite was graded to keep feeding channels open.

The risering system for each casting is described in Table 2 and can be seen in the various figures. It will be appreciated that riser design is not an exact science, but calculations give a first approximation, and represent a systematic approach which is reasonably successful. The same applies to runner design.

CASE STUDIES

1. Casting No. 54

For the risering system shown in Fig. 3 and Table 2 (melt No. 1), the major defects revealed by X-ray radiographic analysis were random inclusions of slag and gas, and/or shrinkage porosity (> level 5) in the junction between the flange and the body in the area away from the side riser (Figs. 3 and 5). There was some shrinkage at the junction of the square mounting legs and the body, and at the nozzle-body junctions in the side opposite to the nozzle risers.

The following steps were taken to minimize defects.

(i) Core venting was increased to reduce gas porosity,

(ii) A second blind riser was added on the opposite side of the flange to improve feeding,

(iii) Chilling on the square mounting legs and the circular flange was increased,

(iv) In the nozzles connected to risers, the height of the chromite- sand chilling in the cores was increased, on the side away from the riser,

(v) An "open" riser was added to the body to improve feeding,

(vi) Sprue, runners and gates were modified as discussed, to achieve lower flow rates (thus reducing gas and dross inclusions), and a better hot-metal distribution (thus increasing the riser effectiveness).

These revised gating and risering systems (Fig. 6), produced class 2 type castings in both 90/10 and 70/30 Cu-Ni alloys. The negligible micro-porosity observed was at the junctions of the square mounting legs and the body.

2. Casting No. 57-2

For the gating and risering system shown in Fig. 4, the major defects, as indicated in Figs. 7 (a) and (b), were:

(a) some isolated inclusions of slag,

(b) severe shrinkage porosity (> level 5) at the junctions between the body and the flange which had only one riser (see Fig. 4),

(c) shrinkage porosity at the junctions of the body and the square mounting flange, between the two square mounting flanges (see Fig. 8), and in the area behind the single riser on the flange.

The following steps were taken to minimize the above defects:

(i) The pouring rate was reduced by increasing the choke at the sprue exit, and the metal velocity was reduced by increasing the number of gates. This allowed more time for the mould and core gases to escape.

(ii) Core venting was increased.

(iii) Feeding was increased by adding a riser to the flange that had one riser.

(iv) A small top riser was added to the body in the region of the square mounting flange.

(v) Hot-metal distribution was improved by running down both sides of the casting and by gating into all four flange risers.

(vi) Chilling on the circular and square mounting flanges was increased.

These modifications (Fig. 9) improved the casting quality in the 90/10 alloy (melt No. 5), and shrinkage porosity was reduced to level 2. There was very little microporosity between the square mounting flanges or between the body and the circular flange junctions in the cope. However, in the case of the 70/30 alloy (melt No. 4), although the overall casting quality was much improved, shrinkage porosity (level 5) was still observed between the body and the circular flanges (cope), and between the body and the square mounting flanges (see Fig. 10).

To improve further the quality of the 70/30 casting, two changes were considered. The first was to add one riser at the top of the body to feed the square mounting flange, and another to the nozzle to feed the nozzle-flange area. This would provide local feed metal but would unfortunately reduce the overall thermal gradient. The second change was to increase chilling of all flanges to increase the thermal gradient. The first change was chosen for convenience and flexibility. The modified risering system (Fig. 11 and

Tables 1 and 2) improved the casting quality to level 1 in the circular flanges. However, some level 2 porosity remained in the body in the region between the two square mounting flanges.

MICROSTRUCTURE

Typical optical micrographs obtained from the test-bar castings of the 90/10 and 70/30 Cu-Ni alloys, are shown in Figs. 12(a) and (b). Figure 12(b) shows vein-like silicide precipitates in the interdendritic areas. Such silicides are not seen in 90/10 alloys, because of the low silicon content. An interesting feature of the 90/10 alloys is the presence of some faceted phases. Electronprobe microanalysis showed these phases to be rich in Si, Nb, Ni and to include some Cu.

TENSILE PROPERTIES

Tensile properties of the test-bar castings are summarized in Table 3 together with those of specimens machined from one of the flanges in casting No. 57-2. From Table 3, it will be seen that separately cast test-bars exceed the requirements of ASTM B369-78. Small specimens machined from the flange of casting 57-2 (melt No. 4) showed slightly higher yield strength and slightly lower elongation, perhaps because they are smaller than standard size. (In spite of the high mechanical properties achieved in the flange itself, the casting was rejected because of shrinkage between the flanges and the body.)

SUMMARY AND CONCLUSIONS

1. Two ship's sets each of eight castings, were successfully produced in niobium-modified 90/10 and 70/30 Cu-Ni alloys. All 16 castings passed the 400 psi (2760 kPa) pressure test and met the mechanical properties specified in ASTM B369-78. In addition, all were judged to meet the ASTM radiography requirements either in toto, or at least in critical areas.
2. Hot-metal distribution was improved by using a non-pressurized gating system and by gating into most of the side risers. The measured pouring rate varied from 5 to 8 lb/sec (2.3-3.6 kg/sec).
3. The average casting yield was about 50%. To have achieved the same casting quality without the use of insulated blind risers and chills,

would have resulted in a much lower yield. Optimization of casting yield was not attempted because of the limited time available to produce acceptable castings.

4. For similar gating and risering systems, the casting quality was better in the short freezing-range 90/10 alloy. In the 70/30 alloy (intermediate freezing range), there was some shrinkage porosity in regions of low thermal gradient.
5. Technically, the project represents a successful exchange of experience between a commercial foundry and the laboratory, to the mutual benefit of both.
6. Commercially, the project is a considerable achievement in that 16 fully machined high-technology castings were produced in alloys not widely used, to exacting requirements, from Canadian sources, and at competitive cost. That this was achieved after only six months from original concept, is a measure of the cooperation exhibited by all parties, and particularly the foundry management.

ACKNOWLEDGEMENTS

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Opinions, conclusions, or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of their respective managements. Similary, certain commercial products were named for convenience, and there is no implication that other products would not perform equally well.

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Table 2. Risering system and casting quality in 90/10 and 70/30 Cu-Ni castings.

Melt No.	Drawing No.	Fig. No.	Type of melt	Type of riser* and dimensions	Radiographic assessment (Numerical assessment according to ASTM E272)
3	54	6	70/30	Four blind risers** and one open riser+	some shrinkage on mounting leg and inclusion in the body between nozzles (Level 2).
6	54	6	90/10	Four blind risers** and one open riser+	some distributed porosity in cope half of flange (Level 1)
5	57-2	9	90/10	Five blind risers** and one open riser+	- level 2 for body and the nozzles - some shrinkage in cope half of each flange (level 2) - some shrinkage in the body-flange junction and between the square mounting flanges (level 3)
15	57-2	11	70/30	Six blind risers** and two open risers+	- level 1 for both flanges - some shrinkage in the square mounting flanges in the junction between the body and one of the circular flanges and th nozzle-body area close to riser location (level 2)

*Foseco insulating sleeves for all risers

**2.5 in (63 mm) diam x 4 in (102 mm) high

+2.5 in (63 mm) diam x 5 in (127 mm) high

Table 3. Tensile properties of test-bars in 90/10 and 70/30 Cu-Ni alloys.

Melt No.	Casting No.	Type of melt	Wt % Si	Wt % Nb	UTS ksi	UTS (MPa)	0.5% yield strength ksi	0.5% yield strength (MPa)	El % in 2 in. (51mm)
5	57-2	90/10	0.16	0.18	51.1	(352)	29	(200)	22
6	54	"	0.17	0.18	54.9	(378)	32.6	(225)	24
ASTM B369-78 specifications for alloy C962200		"	0.3 max	1.0 max	45	(310)	25	(170)	20
3	54	70/30	0.45	0.67	76.4	(526)	39.8	(274)	27
4	57-2	"	0.41	0.64	76.2	(525)	40.2	(277)	24
15	57-2	"	0.41	0.83	79.4	(547)	44.1	(304)	25
4*	57-2	"	0.41	0.64	78.8	(543)	45.4	(313)	21
ASTM B369-78 specifications for alloy C96400		"	0.5 max	1.5 max	60	(415)	32	(220)	20

*Specimen removed from flange.

0.25 in. (6.3 mm) diameter and 1 in. (2.5 cm) gauge length.

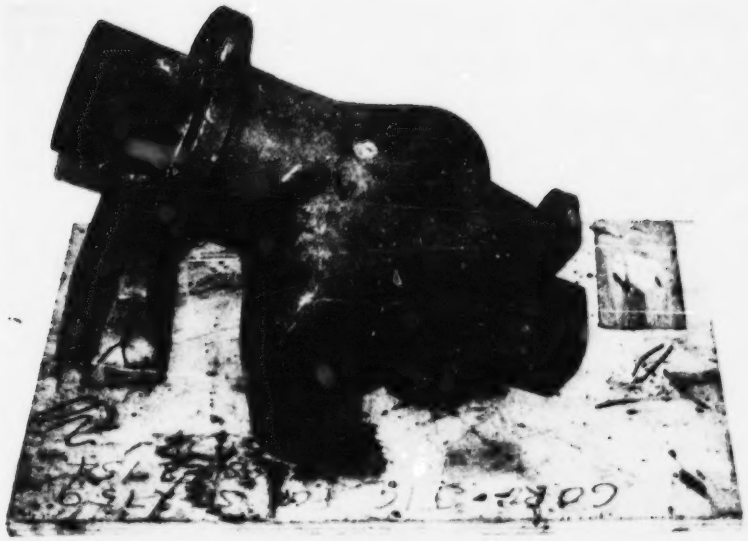


Fig. 1. Photograph of patterns for casting #54.

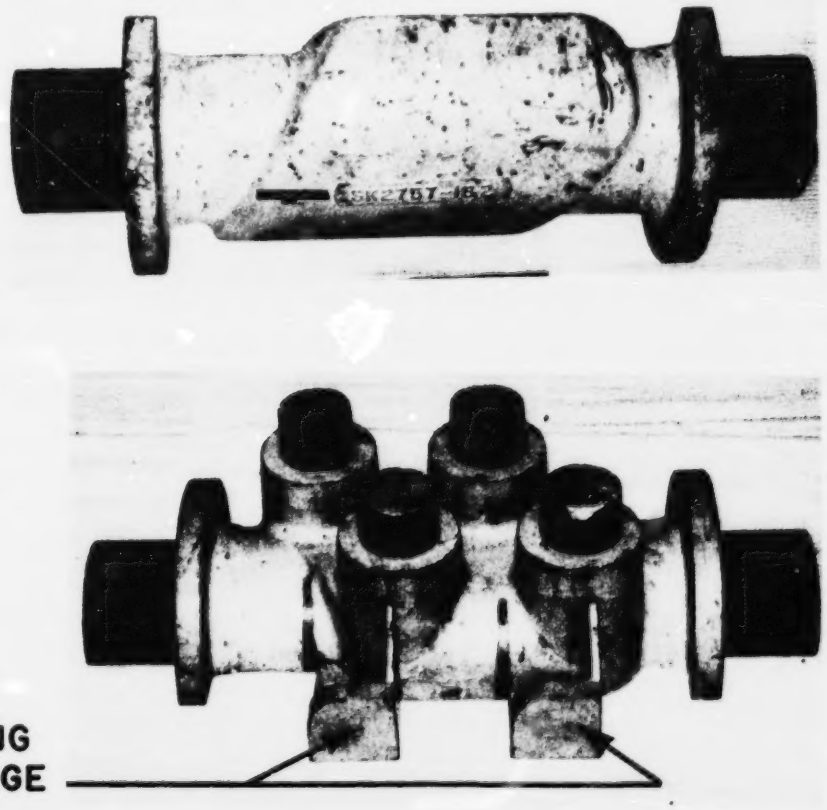
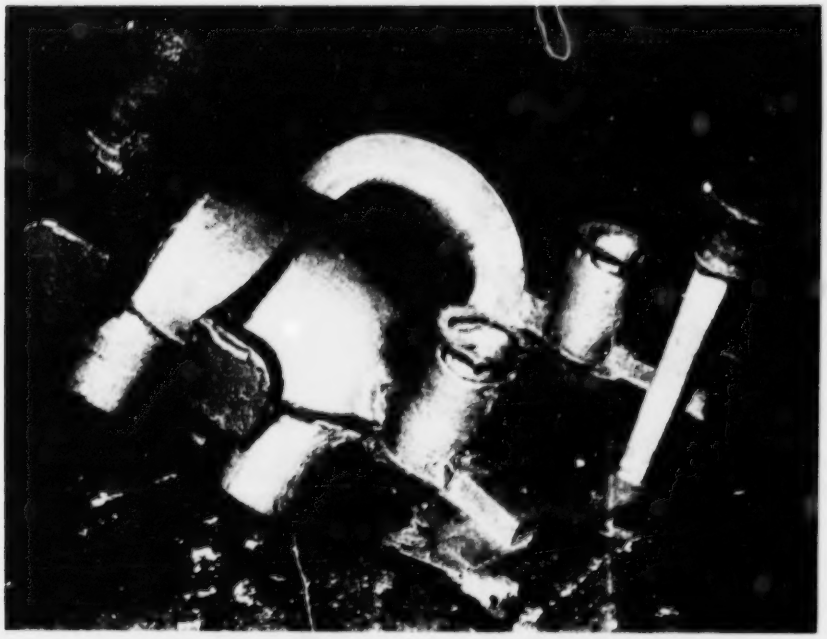
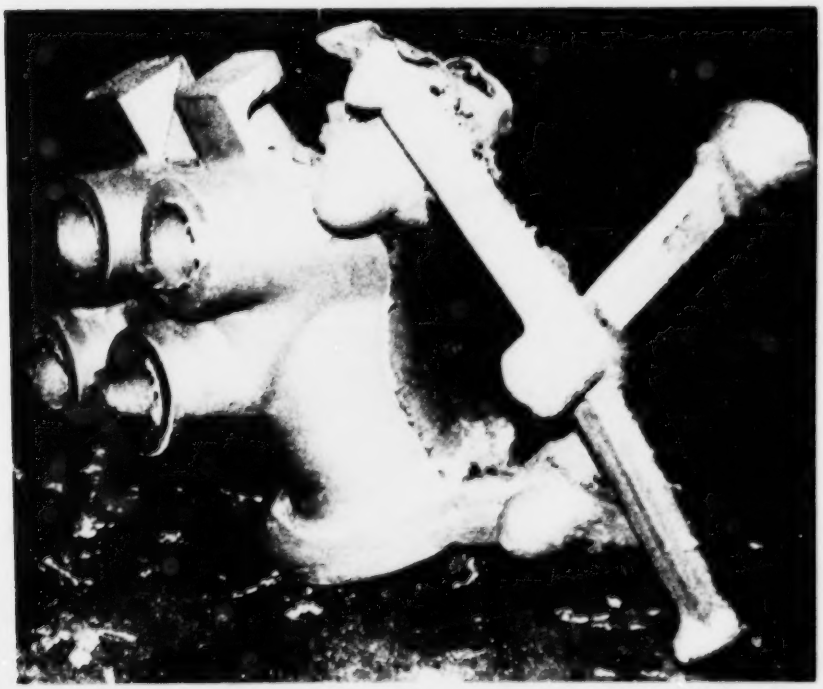


Fig. 2. Photographs of patterns for casting #57-2.

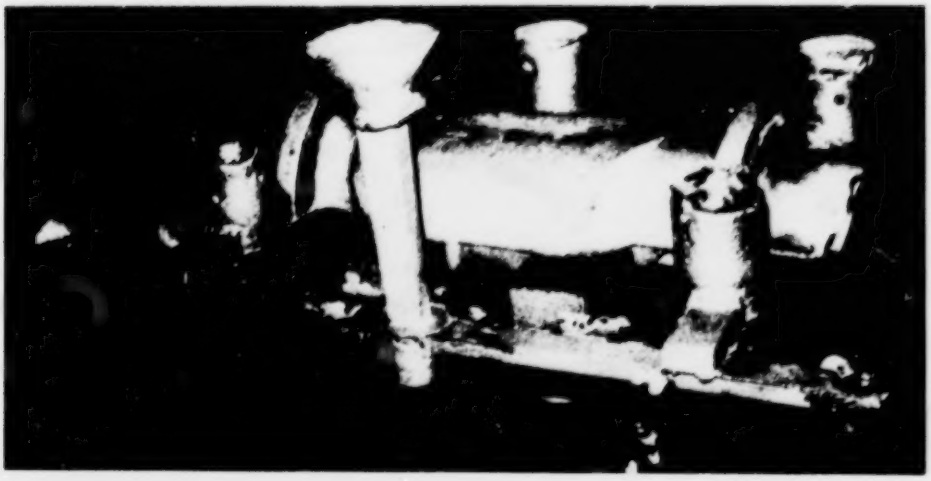


(a) Front

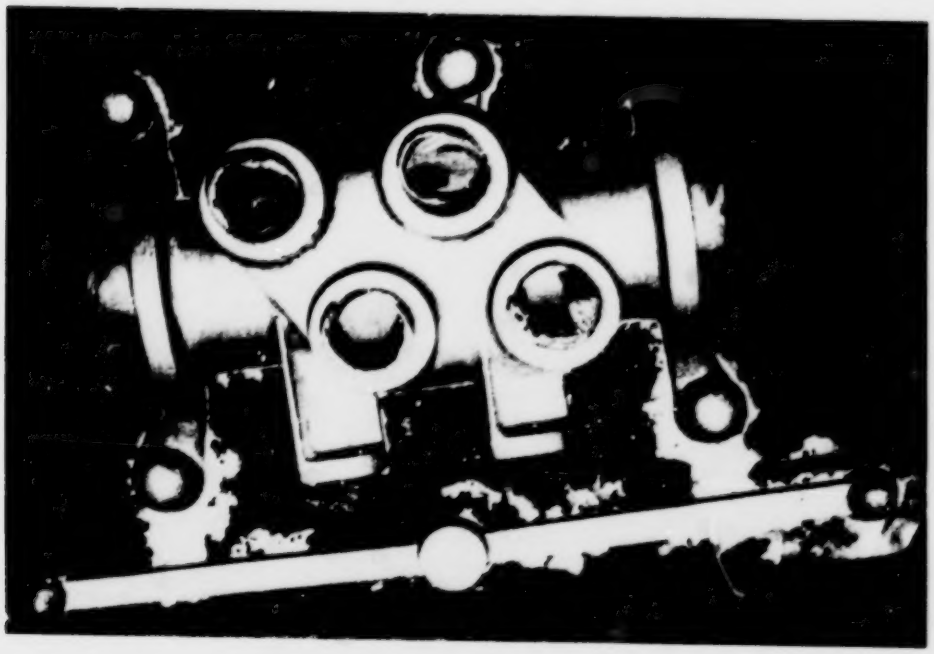


(b) Back

Fig. 3. Casting #54 showing the gating and risering systems (melt no. 1).



(a) Front



(b) Back

Fig. 4. Casting #57-2 showing the gating and risering systems (melt no.2).

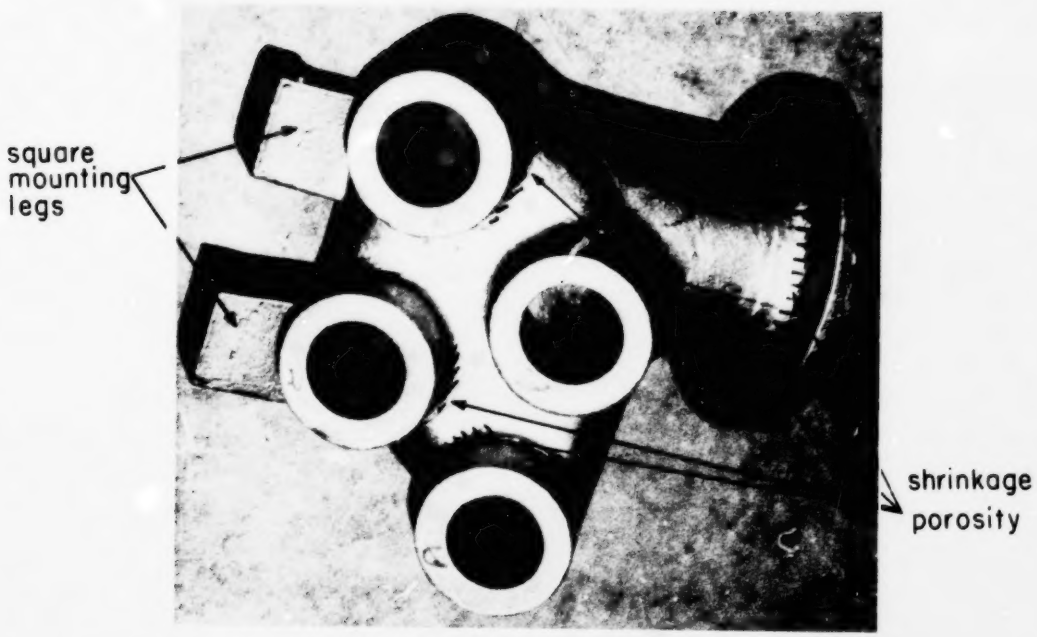


Fig. 5. Photograph of casting #54 (melt no. 1) showing location of shrinkage porosity.

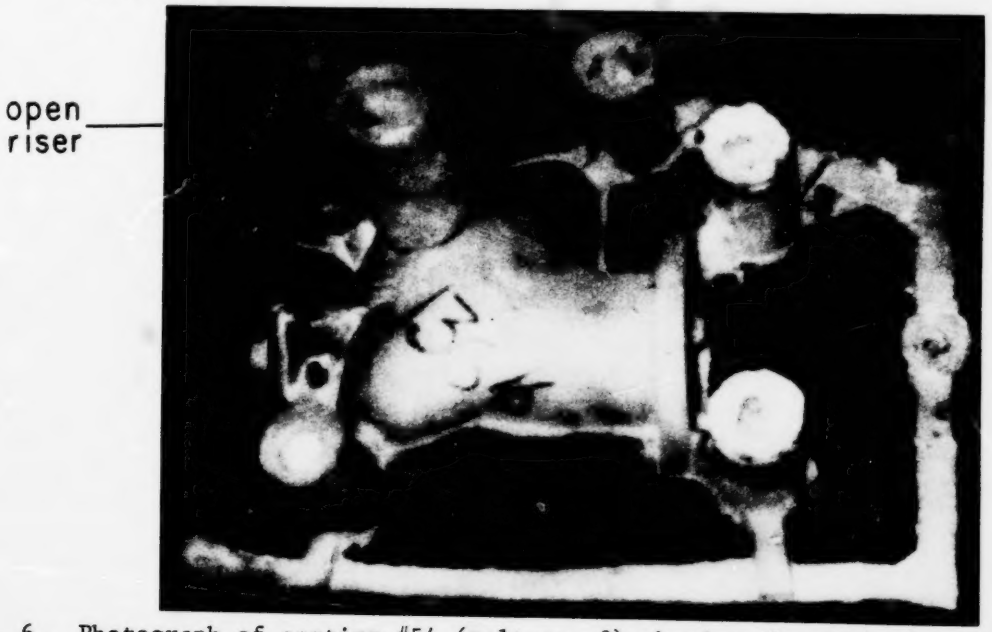
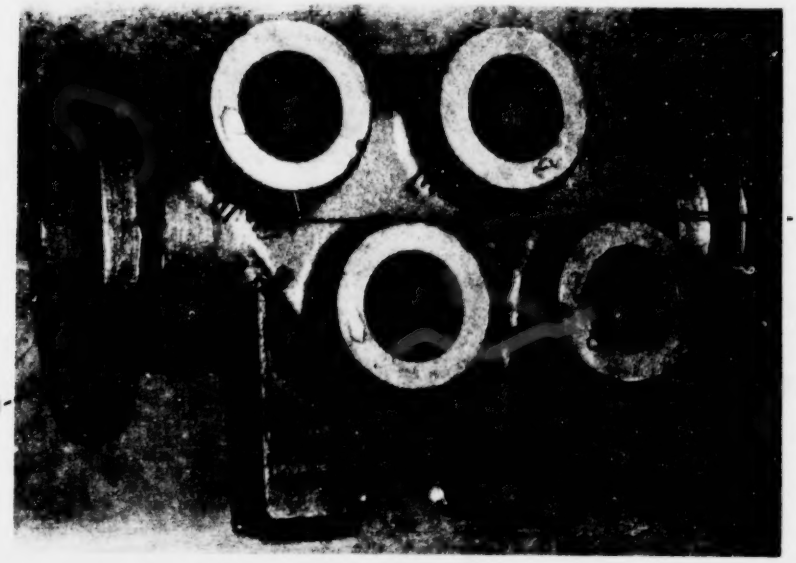


Fig. 6. Photograph of casting #54 (melt no. 3) showing the revised gating and risering systems. (4 blind risers and one open riser).

(a) Shrinkage porosity



(b) Inclusions and porosity

Fig. 7. Photograph of casting #57-2 (melt no. 2) showing location of shrinkage porosity and inclusions.

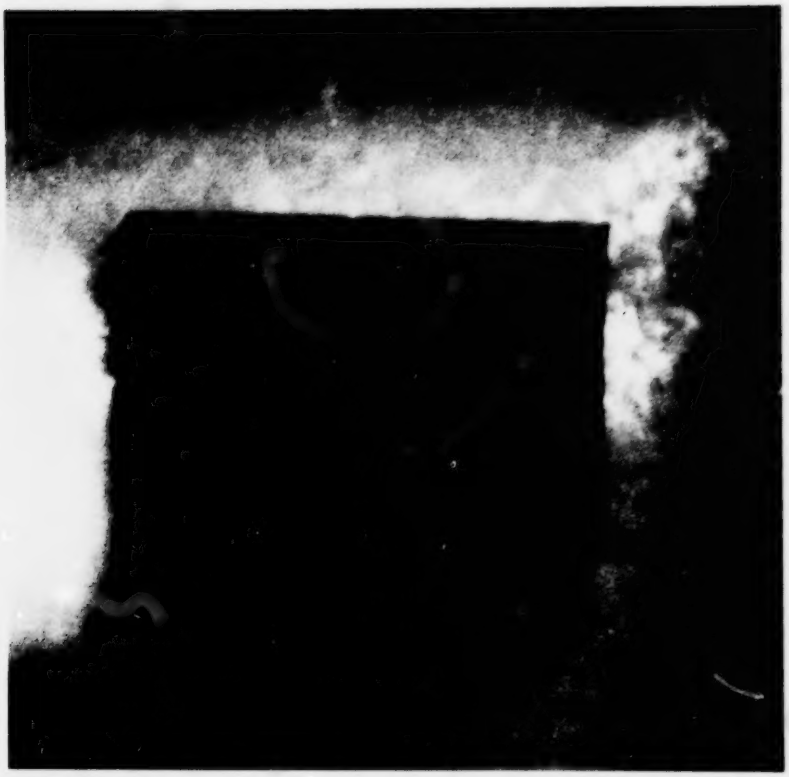


Fig. 8. Print of X-ray image showing shrinkage porosity near the square mounting leg in casting #57-2 (melt no. 2). Shrinkage >5 according to ASTM E272.

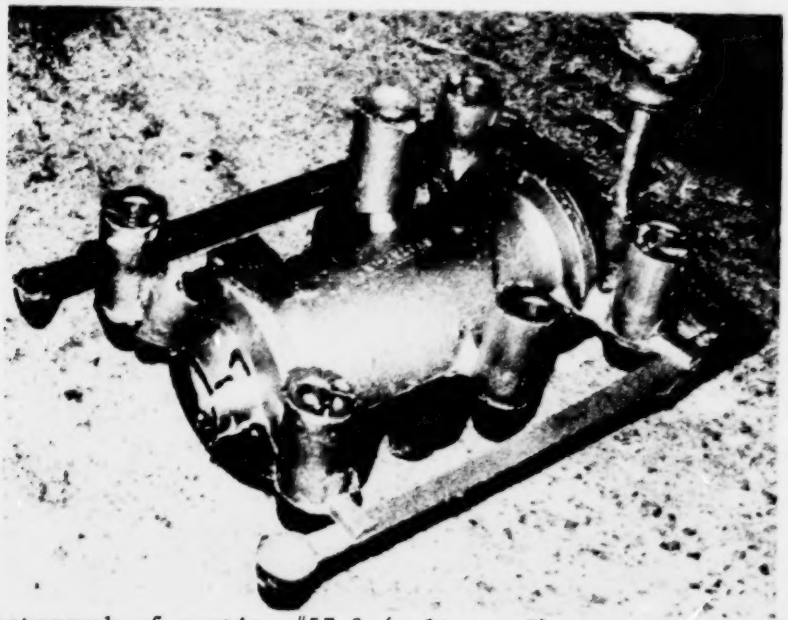


Fig. 9. Photograph of casting #57-2 (melt no. 5) showing the modified gating and risering systems (5 blind risers and one open riser).

Fig. 10. Print of X-ray image showing shrinkage porosity near the square mounting leg in casting #57-2 (melt no. 4) shrinkage level 4 according to ASTM E272.

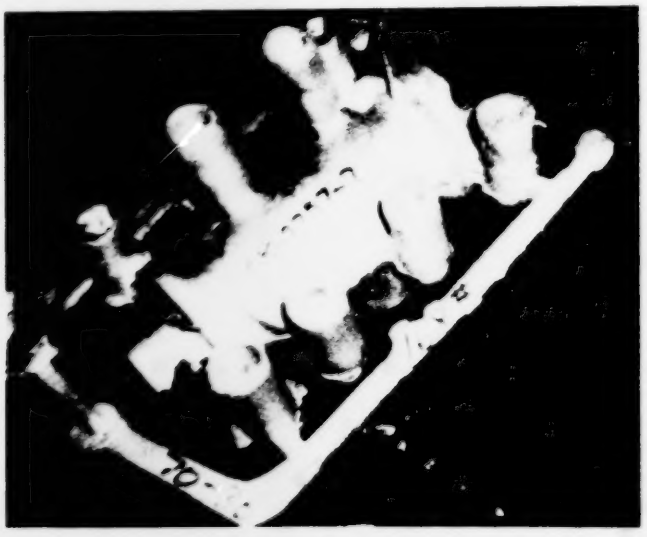
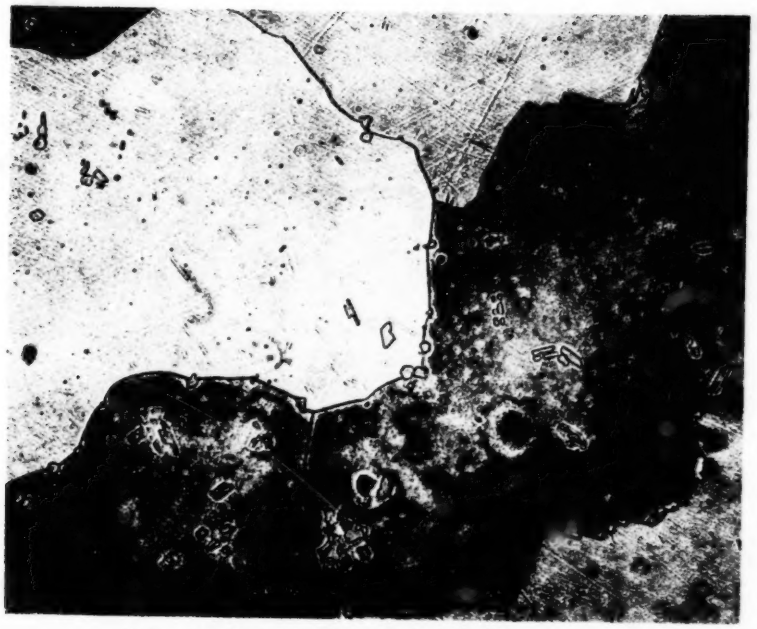


Fig. 11. Photograph of casting #57-2 (melt no. 15) showing the modified gating and risering systems (6 blind risers and 2 top risers).



(a) 90/10 Cu-Ni, melt # 16

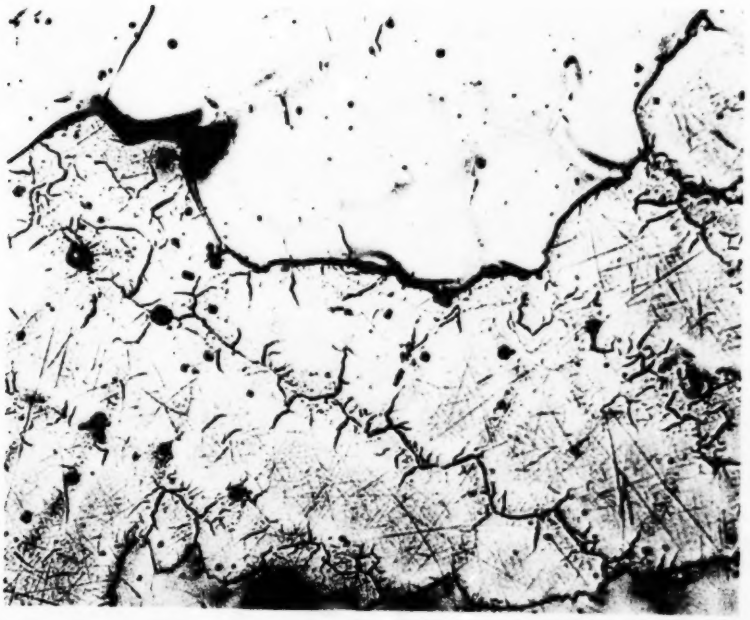


Fig. 12. Optical micrographs of 90/10 and 70/30 Cu-Ni alloys. Alcoholic ferric chloride etch. (X200)

FIGURE #	NEGATIVES #
1	neg with author
2	" " "
3	4248
4	4245
5	4249
6	4246
7 (a) (b)	4253 4254
8	neg with author
9	4261
10	neg with author
11	4256
12(a)	3550
(b)	3551